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Postural stability and ankle sprain history in athletes compared to uninjured controls

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ABSTRACT

Background: Diminished postural stability is a risk factor for ankle sprain occurrence and ankle sprains result in impaired postural stability. To date, ankle sprain history has not been taken into account as a determinant of postural stability, while it could possibly specify subgroups of interest.
Methods: Postural stability was compared between 18 field hockey athletes who had recovered from an ankle sprain (mean (SD); 3.6 (1.5) months post-injury), and 16 uninjured controls. Force plate and kinematics parameters were calculated during single-leg standing: mean center of pressure speed, mean absolute horizontal ground reaction force, mean absolute ankle angular velocity, and mean absolute hip angular velocity. Additionally, cluster analysis was applied to the 'injured' participants, and the cluster with diminished postural stability was compared to the other participants with respect to ankle sprain history.
Findings: MANCOVA showed no significant difference between groups in postural stability ($P = 0.68$). A self-reported history of an (partial) ankle ligament rupture was typically present in the cluster with diminished postural stability. Subsequently, a 'preceding rupture' was added as a factor in the MANCOVA, which showed a significant association between diminished postural stability and a 'preceding rupture' ($P = 0.01$), for all four individual parameters (P: 0.001–0.029; Cohen's d: 0.96–2.23).
Interpretation: Diminished postural stability is not apparent in all previously injured athletes. However, our analysis suggests that an (mild) ankle sprain with a preceding severe ankle sprain is associated with impaired balance ability. Therefore, sensorimotor training may be emphasized in this particular group and caution is warranted in return to play decisions.

1. Introduction

Ankle sprains are the most common injuries in sports, and can lead to a decreased ability to participate in sports and to a decreased quality of life (Janssen et al., 2011). In addition, an ankle sprain can become chronic with symptoms of pain, recurring sprains and a subjective feeling of instability, also referred to as chronic ankle instability (CAI), which may eventually cause ankle osteoarthritis (Anandacoomarasamy and Barnsley, 2005; Harrington, 1979). Despite a substantial body of research, the etiology of ankle sprains and chronic ankle instability is not yet elucidated. However, evidence suggests the existence of a relation between postural stability (throughout this paper this refers to static single-leg stance on a force plate) and ankle sprain risk. Recently, a meta-analysis showed that decreased postural stability is prospectively related to first-time ankle sprain incidence (Witchalls et al., 2012). Additionally, an earlier meta-analysis provided evidence that diminished postural stability is also prospectively related to overall ankle sprain incidence (first-time and recurrent sprains pooled) (de Noronha et al., 2006). It should be noted that postural stability is considered to be a reflection of total body sensorimotor function (Witchalls et al., 2012). As various sensory modalities are used to apply feedback corrections around multiple joints (Hof, 2007; Tropp and Odenrick, 1988), it is difficult to pinpoint specific factors leading to both diminished postural stability and increased risk of ankle sprains.

It is also clear that an ankle sprain could lead to diminished postural stability. During the acute phase (<6 weeks) of an ankle sprain, the postural stability in the injured leg is impaired compared to the non-injured leg (Holme et al., 1999; Leanderson et al., 1996). This may be due to a combination of pathology of ankle structures (ligaments, joint capsule, cartilage, tendons and nerves), inactivity of the affected leg, and/or an arthrogenic muscle response due to pain, damage and edema (Palmieri et al., 2004; Tourné et al., 2010; Yammine and Fathi, 2011). Furthermore, a diminished postural stability has been found in individuals with CAI (Arnold et al., 2009; Wikstrom et al., 2010a), and also in ballet dancers recovered from an ankle sprain in the past year (Lin et al., 2011). The latter finding still needs confirmation for athletes other than dancers, but it could explain the marked increase in incidence during the first 6 months post-injury (Verhagen et al., 2004), as well as the decrease in recurrence risk when sensorimotor training is applied to 'recovered' individuals (Verhagen and Bay, 2010). Previously, De Vries et al. (2010b) have

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shown that postural stability lacks sensitivity for clinical management of ankle sprains when variables such as age, sport type, sport level, length and weight are not controlled for. Therefore, a study in a more strictly defined population of previously injured athletes and matched controls is needed.

Additionally, details of the ankle sprain history may be of importance with regard to the recurrence risk and postural stability. To date, ankle sprain history has not been taken into account in studies on postural stability after ankle sprain injury. As such, a more comprehensive evaluation could indicate specific factors of importance or could specify subgroups in terms of recurrence risk and treatment required.

Therefore, the aim of the present study was (1) to compare postural stability between field hockey athletes with a previous ankle sprain – within 6 months, fully recovered and returned to their pre-injury level of sports participation – and uninjured controls. Furthermore, (2) we aimed to identify characteristics of ankle sprain history present in a subgroup of 'recovered' athletes with strongly affected postural stability.

2. Methods

2.1. Participant recruitment

2.1.1. Inclusion

The age cut-off for entry was 16 to 35 years. As sport type and competition level are confounders of single-leg stance postural stability (Guillou et al., 2007; Kiers et al., 2013; Paillard et al., 2006), all participants were included from one sport type (i.e. field hockey) and had to perform at either inter-district or national level of the official competition. We contacted 26 field hockey teams for recruiting purposes. All coaches of these teams, in consultation with their physical therapist, provided contact information of those players who had endured an ankle sprain in the first 6 months of the season. Subsequently, the researchers contacted these players.

Players who had sustained a self-reported lateral ankle sprain in the past 1 to 6 months, which resulted in at least 2 days off work or 2 missed sport sessions, were eligible for inclusion in the 'previously injured' group. Any form of therapy had to be finished, and a full return to pre-injury sport level participation had to be achieved at the time of inclusion. Players who did not suffer from an ankle sprain in the past five years were eligible for inclusion in the 'uninjured' group. Written informed consent was obtained once the purpose, nature and potential risks had been explained to the volunteers. The study was performed according to the Declaration of Helsinki and approved by the Human Ethics Committee of the Faculty of Human Movement Sciences of the VU University Amsterdam.

2.1.2. Exclusion

The volunteers were screened for the following exclusion criteria: (a history of) musculoskeletal injuries (other than ankle sprain), any other disease that may affect balance performance, head injury in the previous 6 months, and any use of medication that would affect balance.

2.1.3. Power

A minimal effect size of 1 standard deviation was considered to be clinically relevant. Consequently, a minimum of 16 participants in each group was considered sufficient.

2.1.4. Participants

Eighteen participants were included in the 'previously injured' (ankle sprain) group, as illustrated by the inclusion–exclusion flow chart (Fig. 1). The timing of measurement was mean 3.6 (SD 1.5) months post-injury. Sixteen participants were included in the 'uninjured' group. Table 1 outlines the demographic and ankle sprain characteristics. With regard to ankle sprain severity, if a participant went to see a (allied) medical practitioner, the diagnosis made was adopted. If no medical care was sought, a mild sprain (grade I) was assumed, after verification that

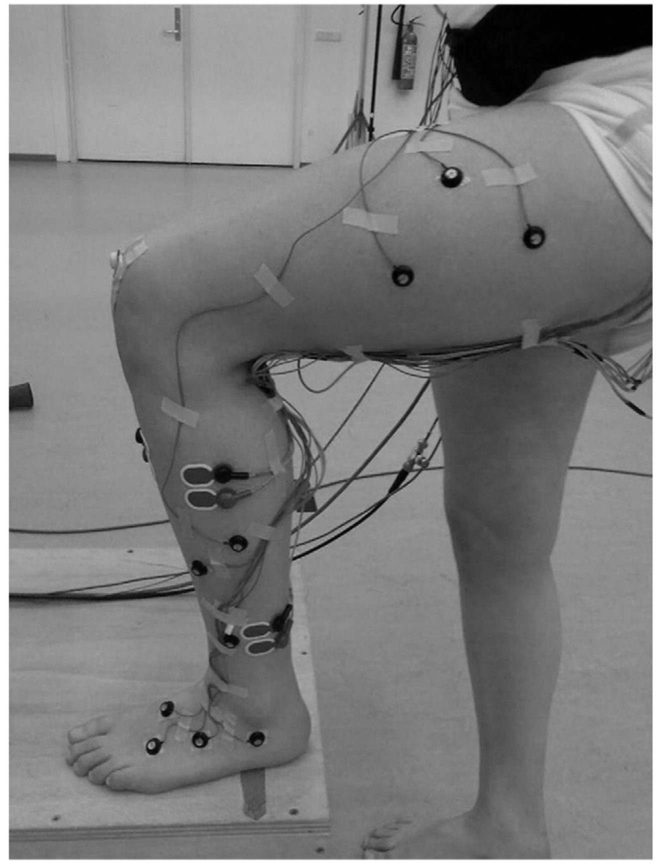

Fig. 1. Typical example of the LED positioning on the foot (4 LEDs), thigh (3 LEDs) and shank (3 LEDs).

these participants had been able to walk within 7 days post-injury, and had not noticed any signs of hematoma discoloration (van Dijk, 2002).

2.2. Experimental task

Participants were asked to perform three valid single-leg stance trials of 20 s with the eyes open for each leg. Participants had to stand as still as possible and keep their hands on their hips. A trial was considered invalid if a participant displaced his/her standing leg, touched the

Table 1
Demographic and ankle sprain characteristics.

	Uninjured	Injured[a]
Men (n)	8	10
Women (n)	8	8
Age (years)[b]	19.1 (2.0)	20.7 (4.4)
Length (m)[b]	1.75 (0.09)	1.80 (0.09)
Weight (kg)[b]	66.9 (9.1)	74.6 (12.5)
Experience (years)[b]	12.4 (2.8)	13.5 (4.5)
Balance therapy past year (%)	0	39
Brace/tape past year (%)	0	72
Preceding (partial) rupture (%)	0	39
>5 sprains past 5 years (%)	0	17
3–5 sprains past 5 years (%)	0	39
1–2 sprains past 5 years (%)	0	44
Bilateral sprains past 2 years (%)	0	39
Medical care (%)[c]	NA	39
Grade II/III sprain (%)[c]	NA	22
Right leg affected (%)[c]	NA	39

[a] Recent ankle sprain past 6 months.
[b] Mean (SD).
[c] With regard to recent ankle sprain.

floor with the contra-lateral leg or if a hand was used to regain balance. All trials were performed with bare feet. All participants were given two practice opportunities with each leg before actual testing commenced. The initial testing leg was randomly assigned, and counterbalanced between the groups.

2.3. Instrumentation

Ground reaction forces (GRF) were sampled at 1000 Hz by a 60 by 40 cm force plate (type 9218B, Kistler Instrument Corp, Winterthur, Switzerland), which was mounted flush with the laboratory floor. A line on the force plate was used to align the foot during the balance tasks. Motion capture data of the lower extremity were collected with the OPTOTRAK® optoelectronic camera system (Northern Digital Inc., Waterloo, Canada), which consisted of two cameras containing three sensors each. The Optotrak system measures the three-dimensional position of light-emitting diodes (LEDs) in a global reference frame. Ten LED markers were attached to the participants' skin on positions with minimal soft tissue deformations during movement (Fig. 2). Additionally, a custom-made aluminum object with three LED markers was positioned over the sacrum. While participants stood upright, facing the positive X-axis of the system, the anatomical coordinate system for each body segment was established by means of digitized bony landmarks (Cappozzo et al., 1995).

2.4. Outcome measures

We assessed postural stability using the following parameters: (1) the 'center of pressure (CoP) speed'; total CoP path length divided by trial time, (2) 'horizontal GRF'; mean length of the GRF vector in the horizontal plane, (3) 'ankle angular velocity'; mean length of the ankle angular velocity vector, and (4) 'hip angular velocity'; mean length of the hip angular velocity vector. The 'CoP speed' has been shown to be reliable (Doyle et al., 2007), and discriminative concerning single-leg stance balance (Jakobsen et al., 2011; Kiers et al., 2013; Paillard et al., 2006; Ross et al., 2009; Wikstrom et al., 2010a). The 'horizontal GRF' is related to the amount of sway of the center of mass and to the corrective shear forces due to counter rotation acceleration of the trunk (Hof, 2007; Pintsaar et al., 1996). This parameter has been shown to be discriminative as well (Pintsaar et al., 1996; Ross et al., 2009). Angular velocities of the ankle and the hip were added since most motor corrections in single leg stance are made by ankle and hip/trunk movements (Hof, 2007; Lin et al., 2011; Tropp and Odenrick, 1988). The ankle sprain characteristics used for subgroup analyses were retrieved through a questionnaire that was completed on the test day, after the experimental testing procedures were finished.

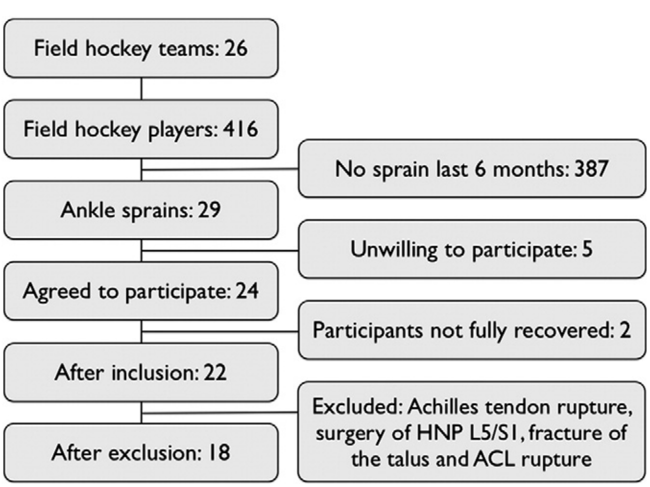

Fig. 2. Flow chart representing inclusion of participants with a previous ankle sprain.

2.5. Data analysis

A custom MATLAB (The Mathworks, Natick, RI, USA) program was written for data reduction. Force plate data and OPTOTRAK data were filtered with a second order Butterworth low-pass filter with estimated optimal cut-off frequencies of 43 Hz and 16 Hz, respectively (Bisseling and Hof, 2006; Yu et al., 1999). CoP calculations were based on vertical and horizontal forces in accordance with the manufacturer's manual. Joint angular velocity vectors were calculated from the instantaneous orientation matrices of the distal relative to the proximal segments according to Berme et al. (1990). Subsequently, the mean angular velocity of a joint was calculated as the average length of these vectors for that joint.

The inter-trial reliability (3 trials) of postural stability measures was determined with the intra-class correlation ($ICC_{2,3}$) analysis for both legs. All four outcome measures showed desirable reliability (>0.80) (Doyle et al., 2007), with all $ICC_{2,3}$ values above 0.920. Subsequently, the calculated outcome measures were averaged over three trials per leg. A preliminary analysis showed no statistical difference between the left and right legs of the uninjured group ($P > 0.05$), therefore, these outcomes were averaged over both legs. With regard to the previously injured group, only the leg with the most recent ankle sprain was considered for analysis. All outcomes were transferred into the Statistical Program for Social Sciences (version 17.0, SPSS Inc., Chicago, IL, USA) for further statistical analysis. Pearson's correlation across all participants showed that the four postural stability parameters were related, but not redundant, with values ranging from 0.70 to 0.88. Therefore, comparison between the previously injured group and the uninjured controls was performed by means of a MANCOVA with the four parameters reflecting postural stability. Since the two groups were not matched for length and weight, both variables were added as a covariate. The Wilks' Lambda test statistic was used, and statistical significance was set at a P-value below 0.05. Furthermore, for each of the postural stability parameters, a follow-up univariate analysis was performed.

To identify a subgroup of previously injured participants with pronounced postural instability, a k-means cluster analysis (function kmeans in MATLAB) was applied to classify previously injured participants in two clusters (Rozumalski and Schwartz, 2009). As the k-means cluster analysis allows one to include an infinite number of variables, the outcomes of 'CoP speed', 'horizontal GRF', 'ankle angular velocity', and 'hip angular velocity' were all included in the analysis. This resulted in a cluster with 'low' values and a cluster with 'high' values. The 'high value' cluster represents a group of previously injured participants with higher postural instability. Consequently, we compared ankle sprain history between both clusters, to explore whether this cluster differed in terms of details of their ankle sprain history. To that end, we determined the percentage of participants showing a specific characteristic in the 'high value' cluster. Based on these values, the most important ankle sprain characteristic was identified and added as a fixed factor into the MANCOVA to verify the relation with postural stability.

3. Results

The MANCOVA (Table 2) Wilks' Lambda revealed no significant effect of a previous ankle sprain in the past 6 months on the postural stability ($P = 0.683$). With a grand total of 4 failed trials in the 'previously injured' group with regard to the affected leg, and 7 failed trials in the 'uninjured' group concerning either leg, a bias due to failed trials is very unlikely.

Cluster analysis identified a 'high value' cluster consisting of 8 'previously injured' participants (Fig. 3). Per self-reported ankle sprain characteristic, Fig. 4 depicts the percentage of participants belonging to the 'high value' cluster. A self-reported 'history of (partial) ankle ligament

Table 2
Postural stability — uninjured versus recovered athletes.

	Uninjured (n = 16) Mean (SD)	Recovered (n = 18) Mean (SD)	Difference	Cohen's *d*	*P*-value[a]
Mean CoP speed (mm s^{-1})	48.02 (12.89)	54.06 (13.94)	12.6%	0.44	0.321
|Mean| horizontal GRF (N)	3.60 (1.10)	4.39 (1.70)	21.9%	0.53	0.509
|Mean| ankle angular velocity (° s^{-1})	8.94 (3.97)	10.27 (3.30)	14.9%	0.36	0.338
|Mean| hip angular velocity (° s^{-1})	5.64 (2.77)	6.22 (3.34)	10.3%	0.18	0.656
Wilks' Lambda					0.683

[a] *P*-value following MANCOVA statistics (Wilks' Lambda) and univariate follow-up analyses.

rupture' was most specific to the 'high value' cluster, as 86% of the participants with a 'partial ligament rupture in the history' belonged to the 'high value' cluster. Furthermore, 75% of the participants that belonged to the 'high value' cluster reported a 'history of (partial) ankle ligament rupture'. Therefore, the association between a 'history of (partial) ankle ligament rupture' and a diminished postural stability was analyzed by adding this characteristic as a factor to the MANCOVA. The results showed that a 'history of (partial) ankle ligament rupture' was significantly associated with diminished postural stability ($P = 0.013$). Univariate follow-up analysis of the four parameters consistently showed significant effects (*P*: 0.001–0.029; Table 3).

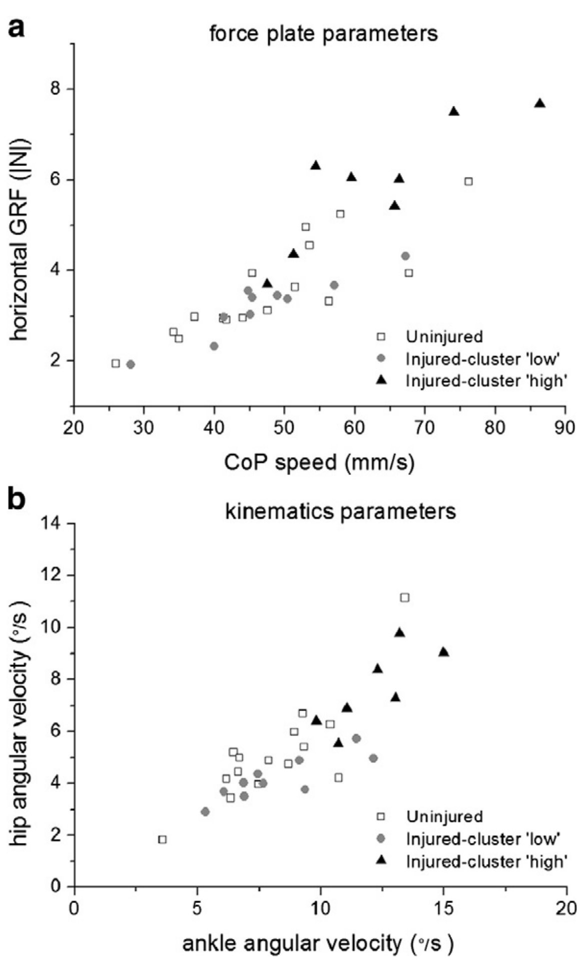

Fig. 3. Postural stability parameter outcome related to the cluster analysis (k-means; k = 2) of the previously injured participants. Panel a shows the force plate parameters, and panel b the angular velocities of ankle and hip. Injured-cluster 'low' represents the previously injured participants in the 'low value' cluster, and injured-cluster 'high' represents the previously injured participants in the 'high value' cluster, i.e. the cluster with higher postural instability.

4. Discussion

The main findings of the present study are twofold. First, field hockey players who have resumed full sport participation after a previous ankle sprain injury (mean 3.6 (SD 1.5) months post-injury) did not show diminished postural stability as a group in a static single-leg stance test compared to uninjured controls. Therefore, it seems that previously injured participants not necessarily have apparent deficits in balance ability. Secondly, our subgroup analysis showed that a history of a (partial) ankle ligament rupture (i.e. severe ankle sprain) was typically present in a cluster of 'recovered' athletes who exhibited diminished postural stability. Subsequently, in a group of athletes who recovered from a recent (mild) ankle sprain, it was shown that a history of a severe ankle sprain was significantly associated with diminished postural stability, with consistent significant values for all four outcome measures (*P*: 0.001–0.029). Therefore, athletes with a history of a severe ankle sprain may be at increased risk of re-injury and may benefit from sensorimotor training. As 50% of the current 'mild' ankle sprains had a history of a severe ankle sprain, this subgroup seems clinically important.

Our findings may be explained by the greater damage of ankle tissue and a longer period of immobilization following a severe ankle sprain, when compared to a mild ankle sprain (Tourné et al., 2010; van Dijk, 2002; Yammine and Fathi, 2011). Additionally, the prolonged inactivity and an altered ankle function might lead to ipsilateral diminished hip functioning, which has been related to CAI and diminished postural stability as well (Allet et al., 2012; Brown et al., 1995; Friel et al., 2006; Gribble and Hertel, 2004). It is possible that an ankle sprain recurrence most frequently occurs in those individuals who exhibit prolonged diminished postural stability following a preceding severe ankle sprain. As one third of all severe ankle sprains in athletes who perform strenuous sports, results in recurrence within the first year (Haraguchi et al., 2009), severe ankle sprain could lead to diminished postural stability in a considerable number of athletes. Therefore, it seems that those individuals with a 'severe' ankle sprain may be particularly important to consider for postural stability testing and sensorimotor training. Unfortunately, the present data is insufficient to evaluate this assumption. Future research may focus on three different groups of ankle sprain patients: (1) a mild ankle sprain with no history of a severe ankle sprain, (2) a mild ankle sprain with a history of a severe ankle sprain, and (3) a first-time severe ankle sprain.

The absence of a significantly diminished postural stability in 'recovered' field hockey players contrasts with the findings of Lin et al. (2011), who showed diminished postural stability in 'recovered' ballet dancers with a previous ankle sprain compared to uninjured controls. A proper comparison between the studies is difficult, as details on ankle sprain history, including previous ligament ruptures, were not provided. Our result may be explained by our sample that comprised a high rate of 'mild' ankle sprains (78%), which may not result in detectable impaired balance ability. Secondly, sensorimotor training during usual care may have decreased differences between groups, as 38% of our participants reported to have received balance training during usual care. Thirdly, our range of inclusion concerning 'time to injury'

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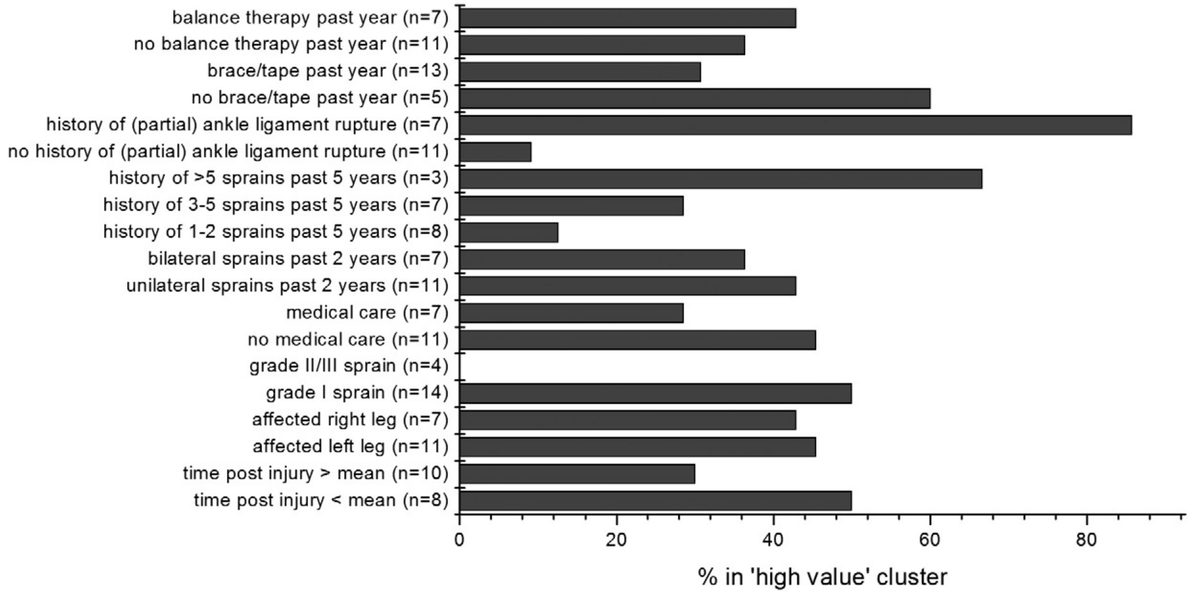

Fig. 4. Ankle sprain characteristics belonging to the ‘high value’ cluster. The number (n) of previously injured participants that reported the ankle sprain characteristic is outlined on the y-axis, while the x-axis represents the percentage of n that belonged to the ‘high value’ cluster, determined through the k-means (k = 2) cluster analysis.

was relatively wide (1 to 6 months). It is conceivable that diminished postural stability is most apparent in the first months post-injury. However, our sample consisted of individuals who were assumed to be ‘fully’ recovered. Therefore, time after injury may be of minor importance, especially in view of the high recurrence rate in recovered individuals up to 6 months post-injury (Hupperets et al., 2009; Verhagen et al., 2004).

While we did not find an overall group difference between participants with and without a previous ankle sprain, it is important to realize that sensorimotor training does reduce ankle sprain recurrence rate in a sample that is comparable to the current sample, in terms of usual care, ankle sprain severity and post-injury time-window (Hupperets et al., 2009). These apparent contradictory findings may be explained by our subgroup finding, as those athletes, who recovered from a ‘mild’ ankle sprain with a ‘severe’ ankle sprain in their history, could be accountable for the preventive effect of sensorimotor training found in athletes who recovered from a ‘mild’ ankle sprain (Hupperets et al., 2009). However, other explanatory alternatives do exist: (1) while it is intuitively appealing, impaired postural stability might not be necessary for preventive sensorimotor training to be effective, (2) the postural stability test might lack sensitivity to establish differences in sensorimotor function, (3) despite the fact that sample characteristics were comparable between studies in terms of ankle sprain severity, usual care and post-injury time window, other sample characteristics may have differed between the studies. In general, our findings highlight the importance of obtaining a detailed ankle sprain history, as it may be useful in interpreting postural stability, recurrence risk and therapy evaluations.

There are a number of limitations concerning the present study that need to be addressed. First of all, this study was performed within a cross-sectional design. Therefore, we can only demonstrate associations and causality cannot be inferred. In general, a postural stability test is considered to be a crude test, as it may be dependent on several factors, such as concentration, environmental disturbances, sport type, sport level, age, length and weight. Therefore, study designs and practical implications of postural stability should be considered in view of these limitations. Furthermore, postural stability is a measure of total-body sensorimotor function. Hence, deficiencies of the postural control system may be compensated for by other parts of this system (Allet et al., 2012). For instance, patients with diminished ankle functioning may use a larger contribution of the ‘hip strategy’ in order to keep their balance (Pintsaar et al., 1996). Therefore, as suggested by Lin et al. (2011), we measured the involvement of the hip by means of kinematics. As we found comparable mean angular velocities of the hip between the previously injured and uninjured groups, a differential involvement of the hip was not apparent. Despite the combination of force plate and kinematics parameters, unknown deficiencies of the system related to ankle sprain risk still might have gone undetected. Additionally, despite a homogenous sample and highly reliable parameters, variance between participants was substantial. Hence, there exists a chance of type II errors when comparing groups. Indeed, the difference between previously injured and uninjured controls was consistent, substantial (10–22%), but not significant. However, the analyses of ankle sprain history imply that the effect is likely due to a specific subgroup, being the participants with a previous ligament rupture.

While it was striking that subjects in the ‘high’ cluster consistently reported a severe ankle sprain in the history, the MANCOVA may have suffered from selection circularity. Because of this, future research

Table 3
Postural stability — no preceding rupture versus preceding rupture.

	No preceding rupture (n = 27) Mean (SD)	Preceding rupture (n = 7) Mean (SD)	Difference	Cohen's *d*	*P*-value[a]
Mean CoP speed (mm s^{-1})	47.79 (11.57)	64.45 (13.39)	34.9%	1.36	0.003
|Mean| horizontal GRF (N)	3.50 (0.96)	5.99 (1.54)	71.1%	2.23	0.001
|Mean| ankle angular velocity (° s^{-1})	8.96 (3.44)	12.32 (3.33)	37.5%	0.96	0.029
|Mean| hip angular velocity (° s^{-1})	5.27 (2.32)	8.58 (4.22)	62.8%	1.16	0.003
Wilks' Lambda					0.013

[a] *P*-value following MANCOVA statistics (Wilks' Lambda) and univariate follow up analyses.

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should confirm our subgroup finding in a specifically tailored research design. Also, there are some ankle sprain characteristics that could have been beneficial for interpretation of our data, but were not determined. The timing of the preceding (partial) rupture, and the ankle sprain frequency subsequent to this rupture, could have provided relevant information. Additionally, our participants performed sport activity at a rather high level, therefore we assumed that the participants did not suffer from CAI, hence no CAI forms were completed (Wikstrom et al., 2010b). However, in view of the ankle sprain frequencies found, some participants might have suffered from mild CAI.

Furthermore, since our analysis suggested that a self-reported history of (partial) ankle ligament rupture is an important characteristic with regard to diminished postural stability, it would have been interesting to know the distribution of mechanical laxity. The most appropriate clinical test to examine the mechanical laxity is the anterior drawer test. De Vries et al. (2010a) have stated that this test is subjective in nature, and that the high intra- and inter-observer variation limits its use, especially for research purposes. Unfortunately, a valid, easy to perform, non-invasive, alternative has not yet been established (de Vries et al., 2010a; Kerkhoffs et al., 2005). Another limitation is that our ankle sprain characteristics are subject to recall bias, as they were provided through self-report.

Finally, the generalization of the present findings could be limited to a moderate to high sport level participation. It seems fair to extend the generalization to other sport types with high ankle sprain incidence rates, like football, volleyball and basketball (Kofotolis and Kellis, 2007; Swenson et al., 2013; Verhagen et al., 2004).

5. Conclusions

As the overall group of athletes who have recovered from a recent ankle sprain (1–6 months) did not show a significant diminished postural stability compared to uninjured controls, it is clear that diminished postural stability is not apparent in all previously injured athletes. However, our analysis indicates that a (mild) ankle sprain with a preceding severe ankle sprain is associated with impaired balance ability. Therefore, sensorimotor training may be emphasized in this particular group and care should be considered for a return to play decision. Finally, the present findings highlight the importance of obtaining a detailed history on ankle sprains, to establish prognostic criteria and relevant group classification of ankle sprains.

References

Allet, L., Kim, H., Ashton-Miller, J., de Mott, T., Richardson, J.K., 2012. Frontal plane hip and ankle sensorimotor function, not age, predicts unipedal stance time. Muscle Nerve 45, 578–585.

Anandacoomarasamy, A., Barnsley, L., 2005. Long term outcomes of inversion ankle injuries. Br. J. Sports Med. 39, e14.

Arnold, B.L., de la Motte, S., Linens, S., Ross, S.E., 2009. Ankle instability is associated with balance impairments: a meta-analysis. Med. Sci. Sports Exerc. 41, 1048–1062.

Berme, N., Cappozzo, A., Meglan, J., 1990. Rigid body mechanics as applied to human movement studies. In: Berme, N., Cappozzo, A. (Eds.), Biomechanics of Human Movement: Applications in Rehabilitation, Sports and Ergonomics. Bertec, Worthington, OH, pp. 89–107.

Bisseling, R.W., Hof, A.L., 2006. Handling of impact forces in inverse dynamics. J. Biomech. 39, 2438–2444.

Brown, C.N., Padua, D.A., Marshall, S.W., Guskiewicz, K.M., 2011. Hip kinematics during a stop-jump task in patients with chronic ankle instability. J. Athl. Train. 46, 461–470.

Cappozzo, A., Catani, F., Croce, U.D., Leardini, A., 1995. Position and orientation in space of bones during movement: anatomical frame definition and determination. Clin. Biomech. 10, 171–178.

de Noronha, M., Refshauge, K.M., Herbert, R.D., Kilbreath, S.L., Hertel, J., 2006. Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? Br. J. Sports Med. 40, 824–828.

de Vries, J.S., Kerkhoffs, G.M.M.J., Blankevoort, L., van Dijk, C.N., 2010a. Clinical evaluation of a dynamic test for lateral ankle ligament laxity. Knee Surg. Sports Traumatol. Arthrosc. 18, 628–633.

de Vries, J.S., Kingma, I., Blankevoort, L., van Dijk, C.N., 2010b. Difference in balance measures between patients with chronic ankle instability and patients after an acute ankle inversion trauma. Knee Surg. Sports Traumatol. Arthrosc. 18, 601–606.

Doyle, R.J., Hsiao-Wecksler, E.T., Ragan, B.G., Rosengren, K.S., 2007. Generalizability of center of pressure measures of quiet standing. Gait Posture 25, 166–171.

Friel, K., McLean, N., Myers, C., Caceres, M., 2006. Ipsilateral hip abductor weakness after inversion ankle sprain. J. Athl. Train. 41, 74–78.

Gribble, P.A., Hertel, J., 2004. Effect of hip and ankle muscle fatigue on unipedal postural control. J. Electromyogr. Kinesiol. 14, 641–646.

Guillou, E., Dupui, P., Golomer, E., 2007. Dynamic balance sensory motor control and symmetrical or asymmetrical equilibrium training. Clin. Neurophysiol. 118, 317–324.

Haraguchi, N., Tokumo, A., Okamura, R., Ito, R., Suhara, Y., Hayashi, H., Toga, H., 2009. Influence of activity level on the outcome of treatment of lateral ankle ligament rupture. J. Orthop. Sci. 14, 391–396.

Harrington, K.D., 1979. Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. J. Bone Joint Surg. Am. 61, 354–361.

Hof, A.L., 2007. The equations of motion for a standing human reveal three mechanisms for balance. J. Biomech. 40, 451–457.

Holme, E., Magnusson, S.P., Becher, K., Bieler, T., Aagaard, P., Kjaer, M., 1999. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. Scand. J. Med. Sci. Sports 9, 104–109.

Hupperets, M.D.W., Verhagen, E.A.L.M., van Mechelen, W., 2009. Effect of unsupervised home based proprioceptive training on recurrences of ankle sprain: randomised controlled trial. BMJ 339, b2684.

Jakobsen, M.D., Sundstrup, E., Krustrup, P., Aagaard, P., 2011. The effect of recreational soccer training and running on postural balance in untrained men. Eur. J. Appl. Physiol. 111, 521–530.

Janssen, K.W., van Mechelen, W., Verhagen, E.A.L.M., 2011. Ankles back in randomized controlled trial (ABrCt): braces versus neuromuscular exercises for the secondary prevention of ankle sprains. Design of a randomised controlled trials. BMC Musculoskelet. Disord. 27, 210.

Kerkhoffs, G.M.M.J., Blankevoort, L., Sierevelt, I.N., Corvelein, R., Janssen, G.H.W., van Dijk, C.N., 2005. Two ankle joint laxity testers: reliability and validity. Knee Surg. Sports Traumatol. Arthrosc. 13, 699–705.

Kiers, H., van Dieën, J., Dekkers, H., Witting, H., Vanhees, L., 2013. A systematic review of the relationship between physical activities in sports or daily life and postural sway in upright stance. Sports. Med 43, 1171–1189.

Kofotolis, N., Kellis, E., 2007. Ankle sprain injuries: a 2-year prospective cohort study in female Greek professional basketball players. J. Athl. Train. 42, 388–394.

Leanderson, J., Eriksson, E., Nilsson, C., Wykman, A., 1996. Proprioception in classical ballet dancers: a prospective study of the influence of an ankle sprain on proprioception in the ankle joint. Am. J. Sports Med. 24, 370–374.

Lin, C.F., Lee, I.J., Liao, J.H., Wu, H.H., Su, F.C., 2011. Comparison of postural stability between injured and uninjured ballet dancers. Am. J. Sports Med. 39, 1324–1331.

Paillard, T., Noé, F., Rivière, T., Marion, V., Montoya, R., Dupui, P., 2006. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. J. Athl. Train. 41, 172–176.

Palmieri, C., Ingersoll, C.D, Hoffman, M.A., Cordova, M.L., Porter, D.A., Edwards, J.E., Babington, J.P., Krause, B.A., Stone, M.B., 2004. Arthrogenic muscle response to a simulated ankle joint effusion. Br. J. Sports Med. 38, 26–30.

Pintsaar, A., Brynhildsen, J., Tropp, H., 1996. Postural corrections after standardised perturbations of single limb stance: effect of training and orthotic devices in patients with ankle instability. Br. J. Sports Med. 30, 151–155.

Ross, S.E., Guskiewicz, K.M., Gross, M.T., Yu, B., 2009. Balance measures for discriminating between functionally unstable and stable ankles. Med. Sci. Sports Exerc. 41, 399–407.

Rozumalski, A., Schwartz, M.H., 2009. Crouch gait patterns defined using k-means cluster analysis are related to underlying clinical pathology. Gait Posture 30, 155–160.

Swenson, D.M., Collins, C.L., Fields, S.K., Comstock, R.D., 2013. Epidemiology of US high school sports-related ligamentous ankle injuries, 2005/06-2010/11. Clin. J. Sport Med 23, 190–196.

Tourné, Y., Besse, J.-L., Mabit, C., 2010. Chronic ankle instability. Which tests to assess the lesions? Which therapeutic options? Orthop. Traumatol. Surg. Res. 96, 433–446.

Tropp, H., Odenrick, P., 1988. Postural control in single-limb stance. J. Orthop. Res. 6, 833–839.

van Dijk, C.N., 2002. Management of the sprained ankle. Br. J. Sports Med. 36, 83–84.

Verhagen, E.A.L.M., Bay, K., 2010. Optimising ankle sprain prevention: a critical review and practical appraisal of the literature. Br. J. Sports Med. 44, 1082–1088.

Verhagen, E.A.L.M., van der Beek, A.J., Bouter, L.M., Bahr, R.M., van Mechelen, W., 2004. A one season prospective cohort study of volleyball injuries. Br. J. Sports Med. 38, 477–481.

Wikstrom, E.A., Fournier, K.A., McKeon, P.O., 2010a. Postural control differs between those with and without chronic ankle instability. Gait Posture 32, 82–86.

Wikstrom, E.A., Tillman, M.D., Chmielewski, T.L., Cauraugh, J.H., Naugle, K.E., Borsa, P.A., 2010b. Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. Scand. J. Med. Sci. Sports 20, e137–e144.

Witchalls, J., Blanch, P., Waddington, G., Adams, R., 2012. Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. Br. J. Sports Med. 46, 515–523.

Yammine, K., Fathi, Y., 2011. Ankle "sprains" during sport activities with normal radiographs: incidence of associated bone and tendon injuries on MRI findings and its clinical impact. Foot 21, 176–178.

Yu, B., Gabriel, D., Noble, L., An, K., 1999. Estimate of the optimum cutoff frequency for the Butterworth low pass digital filter. J. Appl. Biomech. 15, 318–329.

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